Portable Sleep Monitoring System

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RATIONALE

The sleep studies on Neurolab required detailed measurements to assess sleep accurately. On Earth, these measurements would typically be done in a fully equipped sleep laboratory. The operational demands of the Neurolab mission (limited space, power, and time) required a system that could perform all the usual sleep laboratory measurements in a small, portable package. The sleep system assembled for Neurolab included a special suit for measuring respiratory movements, sleep headgear that provided electroencephalography and eye movement data, and a portable recording device that could process and save the information. This system demonstrated that high-quality polysomnographic sleep data could be collected in a very demanding operational environment, and illustrates how sleep could also be monitored routinely in homes and clinics on Earth.

HARDWARE DESCRIPTION

The sleep monitoring system that was developed for this spaceflight experiment consisted of a portable digital sleep recorder, a custom-fitted sleep cap, a respiratory inductance plethysmography body suit, a cable harness, an impedance meter, and a computerized signal-quality assessment system. This system was also used for all preflight and postflight recordings using the same procedures as those used inflight.

Sleep net

Sleep was recorded using a sensor array (e-Net Physiometrix, North Billerica, MA) that was placed on the head. The modified sleep net was an integrated set of components consisting of a reusable customized headpiece and disposable silver/silver chloride hydrogel biosensors (Hydrodot Biosensors, Physiometrix, N. Billerica, MA). The electrophysiological head and face electrode sites were integrated into an elastic lattice cap that was secured on the head by a chin and neck strap. Sleep nets were individually tailored to each subject to ensure proper fit and reproducibility of electrode site placement. The electrodes recorded brainwaves with an electroencephalogram (EEG), eye movements with an electro-oculogram (EOG, left, right outer canthus), and muscular activity around the chin with an electromyogram (EMG, submental). Electrodes were positioned in sockets within the sensor array placed according to the International 10-20 System: two reference electrodes behind the ear, one forehead ground electrode, two EOG electrodes, four EEG electrodes (C3, C4, O1, O2), and four chin EMG electrodes. After placing the electrodes in the sleep net, the function of each electrode was verified by impedance checking prior to each recording (maximum impedance 10 Kohms) The shielded wire leads on the outside of the sleep net were combined into a single connector that attached to the digital sleep recorder (DSR) via a single connector. Figure 1 shows the blue sleep net connected to the digital sleep recorder.

Digital Sleep Recorder

All sleep recordings were acquired on a modified Vitaport-2 DSR (Temec Instruments, Kerkrade, The Netherlands). The

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DSR is a portable, modular battery-operated sleep recorder with a 12-bit digital-to-analog converter (DAC). For the experiments during the Neurolab mission, the DSR consisted of the recorder base with three modules. EEG, EOG, and EMG signals were recorded through the first module. Cardiorespiratory signals were recroded through the second module. The third module, an eight-channel DAC, was used to output acquired signals to other analytical devices. (For details, see Dijk, 2001, and Elliott, 2001.) The 24-channel Vitaport-2 with the DAC attached measured 4×9×15 cm. Data were stored on an 85-Mb Flash random access memory (RAM) card, which provided the capability of recording the Neurolab experiment signals for more than 10 hours using four standard AA batteries. Sixteen channels were used to record and store the data. In addition to the EEG, EOG, and EMG signals, other measurements included respiration via nasal/oral airflow (three-pronged thermistor adhered to upper lip; EdenTec Corporation, Eden Prairie, MN); rib cage and abdominal motion (respiratory inductance plethysmography); snoring (microphone attached to the neck at the level of the larynx); light (detector incorporated into microphone on throat); arterial oxygen saturation via pulse oximetry (SaO_2: Ohmeda Flex-probe; Ohmeda Medical, Inc., Columbia, MD, adhered to left ring finger); heart rate via electrocardiogram (lead II, 256 Hz); and an event marker. The DSR and the harness that connected to it are shown in Figure 1.

Figure 1. The blue sleep net is seen at the top of this figure resting on a white towel. Under the sleep net is the DSR. The DSR connects both to the sleep net and to the harness containing the connectors for the electrocardiogram, pulse oximeter, nasal thermistor, microphone, light sensor, respiratory inductance plethysmograph, and event marker.

EEGs were low-pass filtered at 70 Hz and high-pass filtered with a time constant of 0.33 second and sampled at 256 Hz. To optimize the bandwidth and to limit the size of the data file on the personal computer miniature communications interface adapter (PCMCIA) card, the Vitaport-2 carried out an on-line software moving averaging filtering with a cutoff frequency of 64 Hz, and the EEGs finally were stored at 128 Hz.

EOGs were low-pass filtered at 35 Hz and high-pass filtered with a time constant of one second and sampled at 128 or 256 Hz. An on-line software moving averaging filtering was applied with a cutoff frequency of 32 Hz, and the results were stored at 64 Hz.

EMG signals were low-pass filtered at 100 Hz and high-pass filtered with a time constant of 0.015 second and sampled at 128 or 256 Hz, and the results were stored at 128 Hz.

The data collected on the DSR were stored on PCMCIA 85 MB Flash RAM cards (SanDisk, Sunnyvale, CA). During the STS-90 mission, data were transferred to a microcomputer and downlinked from the Space Shuttle to Mission Control at Johnson Space Center, allowing inspection of the data by the investigators after each inflight sleep recording. Sensor impedances were checked using a NASA-customized impedance meter (inflight) or a GRASS EZM4 impedance meter (pre- and postflight). During and after instrumentation but before sleep, all physiological signals were displayed in real time, on the screen of a laptop, using an expert system for astronaut assistance (Callini, 2000). This allowed inspection of signal quality before the sleep recordings.

Figure 2. The respiratory inductance plethysmograph suit has wires for measuring both chest and abdominal respiratory movements incorporated into the top portion. The shorts have a pocket that holds the DSR. The various Velcro straps are used to route the harness.

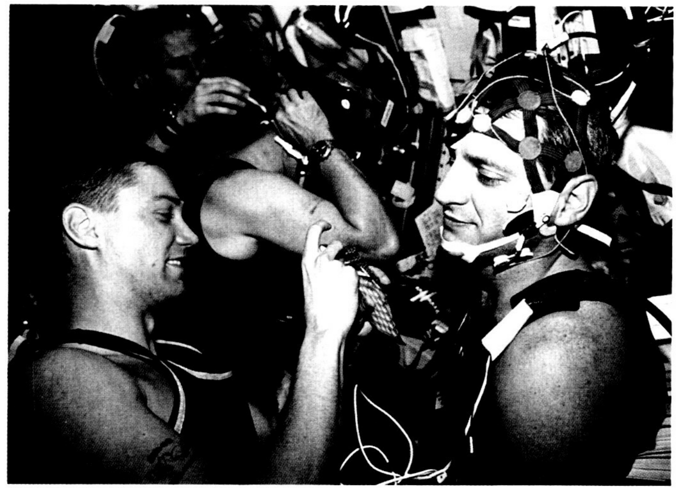

Figure 3. Instrumentation: Payload Specialist Jim Pawelczyk applies hydrogel biosensors to Mission Specialist Rick Linnehan (foreground) while Payload Specialist Jay Buckey arranges straps to secure the sleep net on Mission Specialist Dave Williams (background).

Respiratory Inductance Plethysmograph Suit

The sensors needed to measure the movement of the rib cage and abdomen during breathing (called respiratory inductance plethysmographs) were integrated into a custom-fitted two-piece (vest plus shorts) Lycra body suit (Blackbottoms; Salt Lake City, UT). The suit is shown in Figure 2. The rib cage and abdominal wires for the inductance plethysmography measurements were sewn into the vest section of each suit, with the chest band at the level of the nipples and the abdominal band over the umbilicus. Because the spine lengthens in microgravity, the vest section had adjustable shoulder straps and was held in place by attachment to the shorts with integrated Velcro strips to ensure proper location of each band at all times. A single harness connected all leads from the subject's torso to the DSR.

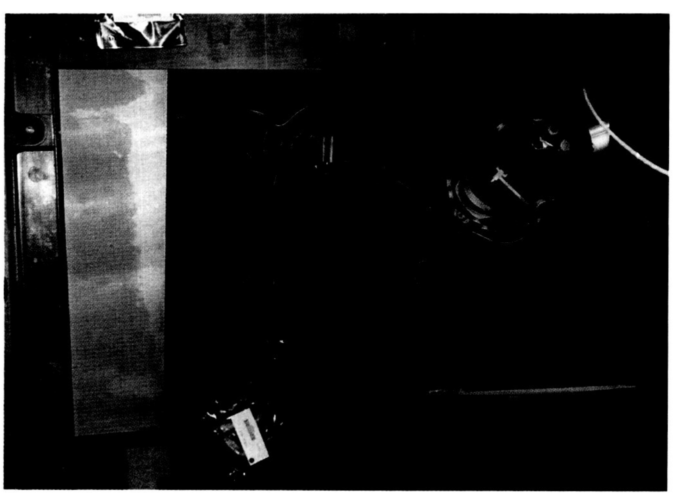

Figure 4. Payload specialist Jay Buckey is shown here, fully instrumented for sleep and resting in the sleep station in the middeck of the Space Shuttle *Columbia*.

Complete Ensemble

During the mission, the astronauts instrumented each other (Figure 3). The resulting complete ensemble is shown in Figure 4. In this picture, a crewmember is fully instrumented and ready for sleep in the sleep station on the Space Shuttle *Columbia*, which has a door slide for darkness and sound attenuation and a built-in ventilation system.

APPLICATION

The sleep ensemble designed for Neurolab could be used to measure sleep in a variety of settings, including patient homes, remote clinics, and hospitals without fully equipped sleep laboratories. It could also be used in studies of sleep in shift workers in the field—e.g. on oil rig workers—the crews of ships, or interns in hospitals.

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